

*(Waves)*



*(Wave Motion)*

: **1-12**



( )

( )

( )

*(mechanical waves)*

*(electromagnetic waves)*

**2-12**

(1-12)

( 1-12)

S

: C B A  
 ( ) S -1

( 2-12) (1-12)

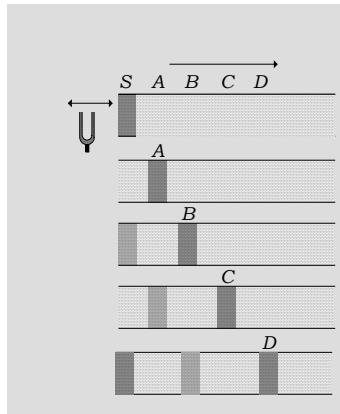
S A

... C B A

-2

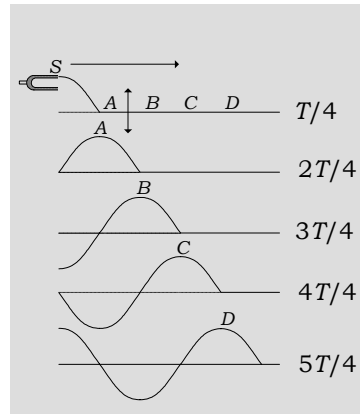
S

.( )



( )

(1-12)



( )

:

( ) -3

.( ... C B A )

( 2-12)

(transverse wave)

.(longitudinal waves)

!

(Wave Equation)

3-12

:

S

(1-12)

$$y_s = A \sin \omega t$$

:

$$f \quad T \quad \omega$$

(2-12)

$$\omega = \frac{2\pi}{T} = 2\pi f$$

(2-12)

p

S

x

:

(3-12)

$$y_p = A \sin \omega(t - t')$$

v

: p S

(4-12)

$$t' = \frac{x}{v}$$

:(3-12)

3-12

(5-12) 
$$y_p = A \sin \omega(t - \frac{x}{v})$$

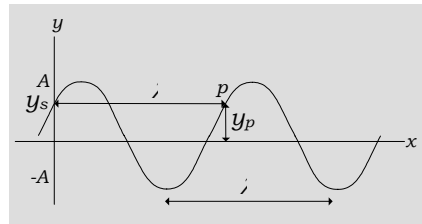
(6-12) 
$$y_p = A \sin(\omega t - \frac{2\pi x}{vT})$$

$vT$

:  $\lambda$  (wavelength)

(7-12)

$$\lambda = vT$$



(2-12)

(2-12)

:  $k$  (wave number)  $2\pi/\lambda$

(8-12)

$$k = \frac{2\pi}{\lambda}$$

:(6-12)

(9-12)

$$y_p = A \sin(\omega t - kx)$$

$x$

(9-12)

$t_0$

$t$

( )

$$y = A \sin(\omega t + \phi)$$

$(\omega t + \phi)$

$$y_s = A \sin \omega t$$

$$y_p = A \sin(\omega t - kx)$$

$x$

*(phase difference)*

$kx$

)

$\pi$

.(

*(in phase)*

$\pi$

$kx$

.(

)

*(out of phase)*

$-A_2$

$A_1$

$x_2 \quad x_1$

(10-12)

$$y_1 = A \sin(\omega t - kx_1)$$

(11-12)

$$y_2 = A \sin(\omega t - kx_2)$$

(13-12)

$$\Delta\phi = k(x_2 - x_1) = k\Delta x = \frac{2\pi}{\lambda} \Delta x$$

(14-12)

$$\Delta\phi = 2n\pi \quad n = 0, 1, 2, \dots$$

(15-12)

$$\Delta x = n\lambda$$

$$\Delta\phi = (2n + 1)\pi$$

(16-12)

$$\Delta x = (2n + 1)\frac{\lambda}{2}$$

**1-12**

$$y_s = 2 \sin 5\pi t \text{ cm}$$

( )

( )

5 m

( ) 30 m/s

( )

A = 2 cm

( ) :

:

$$\omega = 5\pi \text{ rad/s}$$

$$f = \frac{\omega}{2\pi} = 2.5 \text{ Hz}$$

$$T = \frac{1}{f} = 0.4 \text{ s}$$

:

( )

$$\lambda = vT \Rightarrow k = \frac{2\pi}{\lambda} = \frac{2\pi}{vT}$$

$$k = \frac{\omega}{v}$$

:

$$k = 0.52 \text{ m}^{-1}$$

:

( )

$$y_p = A \sin(\omega t - kx) = 2 \sin(5\pi t - 2.6)$$

$$\Delta\phi = 2.6 \text{ rad}$$

( )

**4-12**

:

**-1**

$T$

$\Delta l$

$$(3-12)$$

$v$

$$2T \sin \theta \approx 2T\theta \approx 2T(\Delta l / 2) = T\Delta l / 2$$

$$: \quad mv^2 / r$$

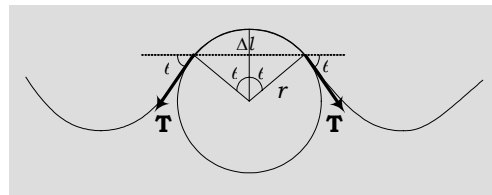
$$T\Delta l / 2 = mv^2 / r = \rho \Delta l v^2 / r$$

:

$$\rho \quad m = \rho \Delta l$$

(17-12)

$$v = \sqrt{\frac{T}{\rho}}$$



(3-12)

200      1 cm      10 N      0.5 m  
50 g

: :

$$\rho = m/l = 50 \times 10^{-3} \text{ kg}/0.5 \text{ m} = 0.1 \text{ kg/m}$$

:

$$v = \sqrt{\rho/T} = \sqrt{(10 \text{ N})/(0.1 \text{ kg/m}^3)} = 10 \text{ m/s}$$

$$: \quad T = 1/f$$

$$\lambda = vT = (10 \text{ m/s})(0.005 \text{ s}) = 0.05 \text{ m}$$

:

$$v = \sqrt{\rho/T} = \sqrt{(20 \text{ N})/(0.1 \text{ kg/m}^3)} = 14.1 \text{ m/s}$$

:

-2

:

(18-12)

$$v = \sqrt{\frac{B}{\rho}}$$

(bulk modulus)

$B$

:

$\rho$



(19-12)

$$v = \sqrt{\frac{\gamma p_0}{\rho}}$$

$p$

$\gamma$

(20-12)

$$v = \sqrt{\frac{Y}{\rho}}$$

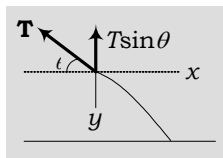
$\rho$

$Y$

1-12

(m/s)		(m/s)	
1190		331	(0 °)
3810		343	(20 °)
5000		1330	
5170		1486	
5200		1519	

**5-12**



(4-12)

$T$

$Fv$

$\Delta l$

(4-12)

$$T_y = -T \sin \theta \approx T \tan \theta = -T \frac{\partial y}{\partial x}$$

$x$

$y$

$\partial y / \partial x$

:

$$\partial y / \partial t$$

$$p = Fv = -T(\partial y / \partial x)(\partial y / \partial t)$$

x t

$$y = A \sin(\omega t - kx)$$

:

$$p = A^2 k \cos^2(\omega t - kx)$$

:

$$p_{av} = \frac{1}{2} A^2 k \omega T$$

:

$$T = \rho v^2 = \rho \lambda^2 f^2 \quad k = 2\pi / \lambda \quad \omega = 2\pi f$$

(21-12)

$$p_{av} = 2\pi^2 A^2 f^2 \rho v$$

(Superposition)

:

**6-12**



$y_1 + y_2$

( )

$y_2$

$y_1$

( )

$$y_1 = A \sin(\omega t - kx)$$

$$y_2 = A \sin(\omega t - kx - \phi)$$

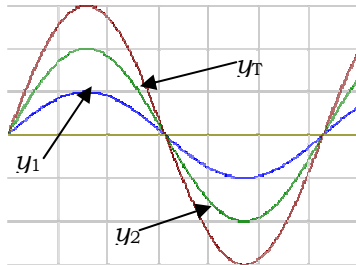
$$y_T = y_1 + y_2 = A \sin(\omega t - kx) + A \sin(\omega t - kx - \phi)$$

$$\sin \alpha + \sin \beta = 2 \sin\left(\frac{\alpha + \beta}{2}\right) \cos\left(\frac{\alpha - \beta}{2}\right)$$

$$(21-12) \quad y_T = [2A \cos(\phi/2)] \sin(\omega t - kx - \phi/2)$$

$$(22-12) \quad y_T = A_{\max} \sin(\omega t - kx - \phi/2)$$

$$(23-12) \quad A_{\max} = 2A \cos(\phi/2)$$



(5-12)

$$n \quad \phi = 2n\pi$$

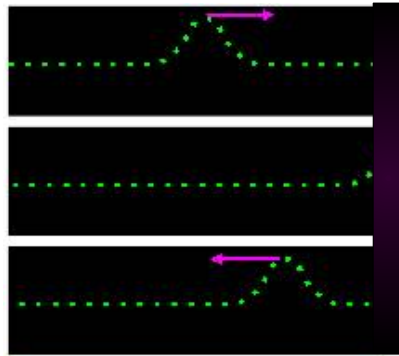
$$(5-12) \quad \phi = (2n+1)\pi \quad A_{\max}$$



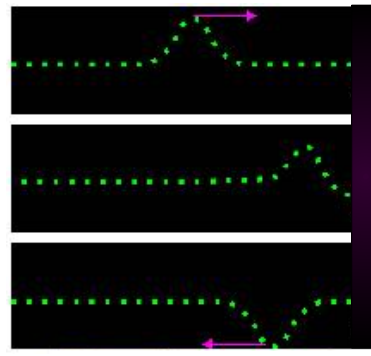
(6-12)

$\pi$

(7-12)



(7-12)



(6-12)

$$y_1 = A \sin(\omega t - kx)$$

$$y_2 = -A \sin(\omega t + kx)$$

(24-12)

$$y_T = y_1 + y_2 = A[\sin(\omega t - kx) - \sin(\omega t + kx)]$$

$$\sin \alpha - \sin \beta = 2 \sin\left(\frac{\alpha - \beta}{2}\right) \cos\left(\frac{\alpha + \beta}{2}\right)$$

(25-12)  $y_T = -[2A \sin(kx)] \cos \omega t$

(26-12)  $y_T = A(x) \cos \omega t$

(27-12)  $A(x) = -2A \sin(kx)$

$\omega$

: ( )  $A(x) = 2A$

$\sin(kx) = \pm 1 \Rightarrow kx = (2n + 1) \frac{\pi}{2} \Rightarrow \frac{2\pi}{\lambda} x = (2n + 1) \frac{\pi}{2}$

(28-12)  $x = (2n + 1) \frac{\lambda}{4} \quad n=0,1,2,\dots$

$\dots, \frac{5\lambda}{4}, \frac{3\lambda}{4}, \frac{\lambda}{4}$

.(crest)  $2A$

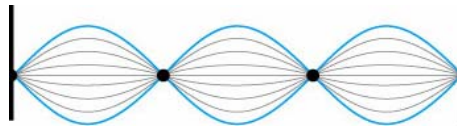
:

$\sin(kx) = 0 \Rightarrow kx = n\pi \Rightarrow \frac{2\pi}{\lambda} x = n\pi$

(29-12)  $x = n \frac{\lambda}{2} \quad n=0,1,2,3,\dots$

$\dots, 2\lambda, \frac{3\lambda}{2}, \lambda, \frac{\lambda}{2}, 0$

(8-12) .(node)



(8-12)

(Resonance)

8-12

$\mu$

$L$

:

$T$

:

-1

(30-12)

$$L = (n + 1) \frac{\lambda}{2}, \quad n=0,1,2,3,\dots$$

$n$

(9-12)

:

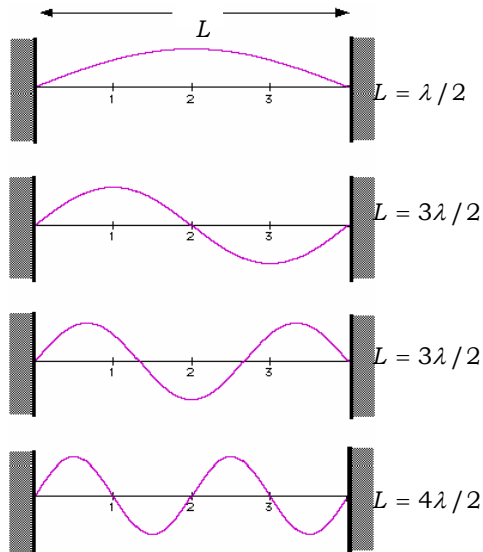
$v$

(31-12)

$$\lambda = \frac{v}{f}$$

: (30-12)

$$L = (n + 1) \frac{v}{2f}$$



(9-12)





$$L = (n + 1) \frac{v}{2f} = (n + 1) \left( \frac{31.6 \text{ m/s}}{150 \text{ s}^{-1}} \right) = (n + 1)(10.5 \text{ cm})$$

$$( \quad ) n=8$$

.94.8 cm

-2

(35-12)

$$L = (2n + 1) \frac{\lambda}{4}, \quad n=0,1,2,\dots$$

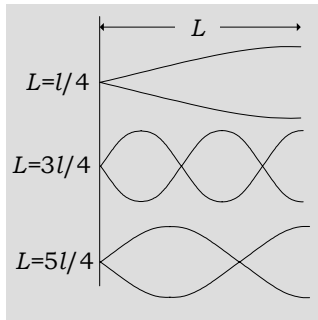
:  $\lambda$

(36-12)

$$L = (2n + 1) \frac{v}{4f}$$

(37-12)

$$f_n = (2n + 1) \frac{v}{4L}, \quad n=0,1,2,\dots$$



(10-12)

$$(38-12) \quad f_0 = \frac{v}{4L}$$

:

$$(39-12) \quad f_n = (2n + 1)f_0, \quad n=0,1,2,\dots$$

(10-12)

(Sound)

**9-12**

(17-12)

(40-12)

$$v = \sqrt{\frac{\gamma RT}{M}}$$

$T$   $R=8.314 \text{ J/mol.K}$   
 $V$   $\rho$

$R$

$\gamma$

$M$

$n$

(41-12)

$$\rho = \frac{nM}{V}$$

(1 atm)

.340 m/s

(20 °C)

(Sound Intensity & Intensity level)

**10-12**

:

$I$

(42-12)

$$I = \frac{p}{A}$$

.W/m<sup>2</sup>

20,000 Hz 20 Hz

$I_0$

1 W/m<sup>2</sup> 10<sup>-12</sup> W/m<sup>2</sup>

: (intensity level)

(43-12)

$$\beta = 10 \log_{10} \left( \frac{I}{I_0} \right)$$

:

(Bel)

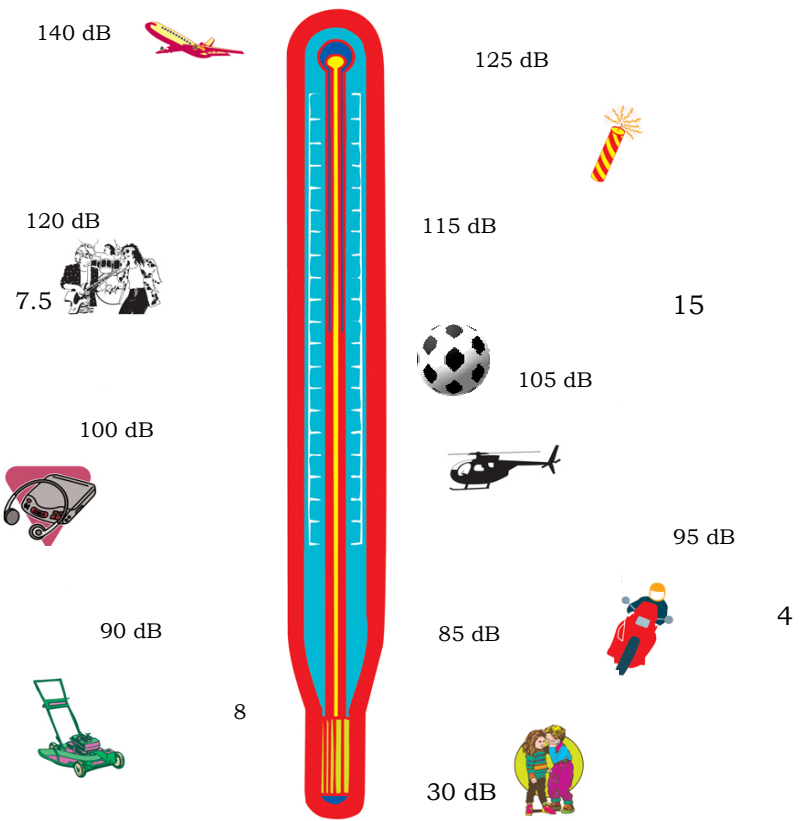
.(dB)

:  $I$   $r$

(44-12)

$$I_r = \frac{I}{4\pi r^2}$$

(11-12)



(11-12)

1 mW  
5 m

(44-12)  $5 \text{ m}$

$$A = 2\pi r^2 = 2\pi(5 \text{ m})^2 = 157 \text{ m}^2$$

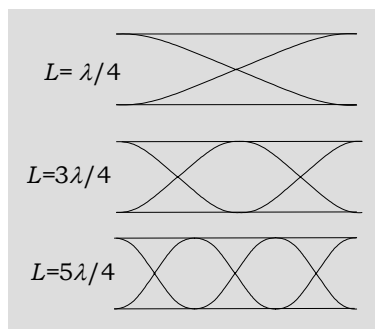
$$I = p/A = (1 \text{ mW})/(157 \text{ m}^2) = 6.37 \text{ } \mu\text{W}/\text{m}^2$$

: (43-12)

$$\beta = 10 \log_{10} \left( \frac{I}{I_0} \right) = 10 \log_{10} \left( \frac{6.37 \times 10^{-6}}{10^{-12}} \right) = 68 \text{ dB}$$

!

$L$  ( )



(12-12)

:(12-12)

-1

(45-12)

$$L = (n + 1) \frac{\lambda}{2}$$

(46-12)

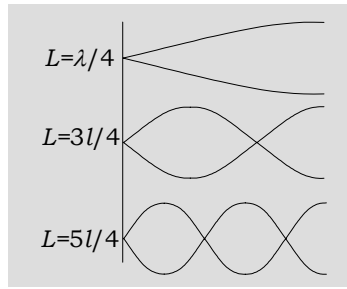
$$f_n = (n + 1) \frac{v}{2L}, \quad n=0,1,2,\dots$$

(47-12)

$$f_0 = \frac{v}{2L}$$

(48-12)

$$f_n = (n + 1)f_0, \quad n=0,1,2,\dots$$



(13-12)

(13-12)

-2

$$L = (2n + 1) \frac{\lambda}{4}$$

(50-12)

$$f_n = (2n + 1) \frac{v}{4L}, \quad n=0,1,2,\dots$$

(51-12)

$$f_0 = \frac{v}{4L}$$

(52-12)

$$f_n = (2n + 1)f_0, \quad n=0,1,2,\dots$$

6-12

( ) 1 m

$$f_0 = \frac{v}{2L} = \frac{340 \text{ m/s}}{2(1 \text{ m})} = 170 \text{ Hz}$$

$$f_3 = 680 \text{ Hz} \quad f_2 = 510 \text{ Hz} \quad f_1 = 340 \text{ Hz}$$

$$y_1 = A \sin \omega_1 t$$

$$y_2 = A \sin \omega_2 t$$

$$y_T = y_1 + y_2 = A \sin \omega_1 t + A \sin \omega_2 t$$

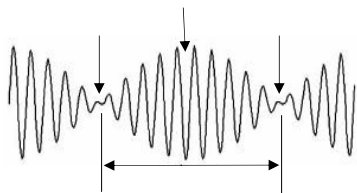
$$(53-12) \quad y_T = 2A \sin\left(\frac{\omega_1 + \omega_2}{2} t\right) \cos\left(\frac{\omega_1 - \omega_2}{2} t\right)$$

$$: (53-12) \quad \omega_1 - \omega_2 = \Delta\omega \quad \omega_1 + \omega_2 = 2\omega \quad \omega_1 \approx \omega_2 = \omega$$

$$y_T = [2A \cos\left(\frac{\Delta\omega}{2} t\right)] \sin \omega t$$

$$(54-12) \quad y_T = A(t) \sin \omega t$$

$$(55-12) \quad A(t) = 2A \cos\left(\frac{\Delta\omega}{2} t\right)$$



(14-12)

$$. (14-12)$$

$$(14-12)$$

$$( \quad )$$

(beat frequency)

$$. \Delta\omega/2$$

$$(56-12) \quad \omega_{beat} = \omega_1 - \omega_2$$

7-12

2%

.300 Hz

$$f \propto v \propto \sqrt{T}$$

$$\frac{f_1}{f_2} = \sqrt{\frac{T_1}{T_2}} = \sqrt{\frac{1.02T}{1.0T}} = 1.01$$

$$f_1 = 1.01 \times 300 = 303 \text{ Hz}$$

$$f_{beat} = f_1 - f_2 = 3 \text{ Hz}$$

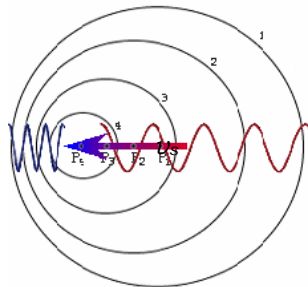
(Doppler's Effect)

13-12

$v_s$

$$(15-12) \quad f$$

$$x = v_s T$$



الشكل (15-12)

$$\lambda' = \lambda - v_s T = vT - v_s T = (v - v_s)T$$

$$f' = \frac{v}{\lambda'} = \left(\frac{v}{v - v_s}\right)f$$

$$\lambda' = \lambda + v_s T = vT + v_s T = (v + v_s)T$$

(58-12)  $f' = \frac{v}{\lambda'} = \left(\frac{v}{v + v_s}\right)f$

$f$   $v_L$

$v' = v + v_L$

:  $\lambda$

$f' = \frac{v'}{\lambda} = \frac{v + v_L}{\lambda}$

:

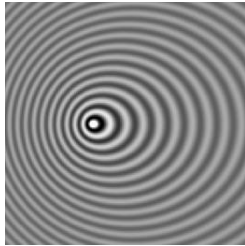
(59-12)  $f' = \left(\frac{v + v_L}{v}\right)f$

:

(60-12)  $f' = \left(\frac{v - v_L}{v}\right)f$

:

(61-12)  $f' = \left(\frac{v \pm v_L}{v \mp v_s}\right)f$



**8-12**

1000 Hz

20 m/s

340 m/s



20 m/s  
 : (61-12)

$$f' = \left(\frac{v + v_L}{v - v_s}\right)f = \left(\frac{340 + 20}{340 - 20}\right)1000$$

.  $f' = 1125 \text{ Hz}$

$$y_p = A \sin(\omega t - kx)$$

$$k = 2\pi / \lambda$$

$$\lambda = vT$$

$$\Delta\phi = 2n\pi$$

$$\Delta\phi = (2n + 1)(\pi / 2)$$

$$v = \sqrt{T / \rho}$$

$$v = \sqrt{\gamma RT / M}$$

$$y_T = [2A \cos(\phi / 2)] \sin(\omega t - kx - \phi / 2)$$

$$\Delta x = (2n + 1)(\lambda / 4)$$

$$\Delta x = n\lambda / 2$$

$$f_n = (n + 1)(v / 2L)$$

$$f_n = (n + 1)(v / 2L)$$

$$\beta = 10 \log_{10}(I / I_0)$$

$$I_r = I / 4\pi r^2$$

$$f_n = (n + 1)(v / 2L)$$

$$f_n = (2n + 1)(v / 4L)$$

$$\omega_{beat} = \omega_1 - \omega_2$$

$$f' = \left(\frac{v \pm v_L}{v \mp v_s}\right)f$$

8.8 s	120 m			<b>1-12</b>
740 km/h		(tidal waves)		<b>2-12</b>
		8000 km	.300 km	
$y$		$y = 6 \cos(4t + 20x + \pi/3)$		<b>3-12</b>
			$t$	
2 cm		6 m/s	1.2 m	<b>4-12</b>
	( )		( ) . $t=0$	<b>5-12</b>
		20,000	20	
		(1490 m/s	340 m/s	)
	C	60 Hz	C	<b>6-12</b>
			$3 \times 10^8$ m/s	<b>7-12</b>
		.700 nm	400 nm	
.10 m/s		2 cm	60 Hz	<b>8-12</b>
		. $t=0$		
$t$	$y$	$y = \sin(6.28x + 314t)$		<b>9-12</b>
		( )	( )	( ) .
5 g	70 cm			( ) <b>10-12</b>
				( ) 500 N
				.
900 N	100 g	7 m		<b>11-12</b>
110 N	700 g	10 m		<b>12-12</b>

13-12

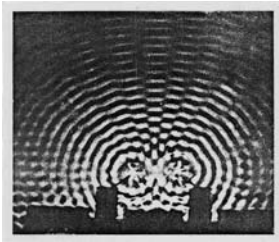
$\pi/3$

3 cm

14-12

.( )  $\pi/2$  4 cm

$y_2 = 6 \cos(\pi x + 4\pi t)$   $y_1 = 6 \cos(\pi x - 4\pi t)$  15-12  
( ) ( ) . t



(16-12)

d S<sub>2</sub> S<sub>1</sub> 16-12

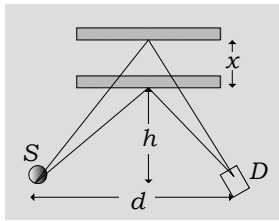
( )

(16-12)

s 17-12

(17-12)

h



(17-12)

1 m

$\lambda$

x h d

h+x

( ) 18-12

968 N

5 g

( )

60 Hz

3 m

19-12

.4 mm

3 m

20-12

50 m/s

$y = 5 \sin(25x) \cos(5t)$

21-12

( ) . t y

( )

( )

	160 g	4 m	<b>22-12</b>
400 N			.
	.340 m/s		38-23
	10 m		<b>23-12</b>
			<b>24-12</b>
	7.5 m		<b>25-12</b>
	$10^{-2} \text{ W/m}^2$	$10^{-10} \text{ W/m}^2$	<b>26-12</b>
	30 dB	10 dB	<b>27-12</b>
.3 dB			<b>28-12</b>
70 dB	90 dB		<b>29-12</b>
( ) .200 Hz		17 m/s	<b>30-12</b>
	( )		( )
			( )
17 m/s			<b>31-12</b>
		80 m/s	<b>32-12</b>
		( ) .200 Hz	
			<b>33-12</b>
		80 m/s	80 m/s
.200 Hz		80 m/s	<b>34-12</b>

			:	
.200 Hz		80 m/s		<b>35-12</b>
3 rev/min	1 m			<b>36-12</b>
		.200 Hz		
				<b>37-12</b>
3				
km/s				
	196 Hz	30 cm		<b>38-12</b>
	262 Hz	247 Hz	220 Hz	
360 N		$4 \times 10^{-3} \text{ kg/m}^3$		<b>39-12</b>
		( ) .450 Hz		375 Hz
2358	1834 Hz	1310 Hz		<b>40-12</b>
( )		( )		( ) .Hz
	440 N	1 g	0.5 m	<b>41-12</b>
18 cm				
		( )		
	40 MHz			<b>42-12</b>
		.39.958 MHz	90 ms	
			1.54 km/s	
	2.0 GHz			<b>43-12</b>
				.293 Hz